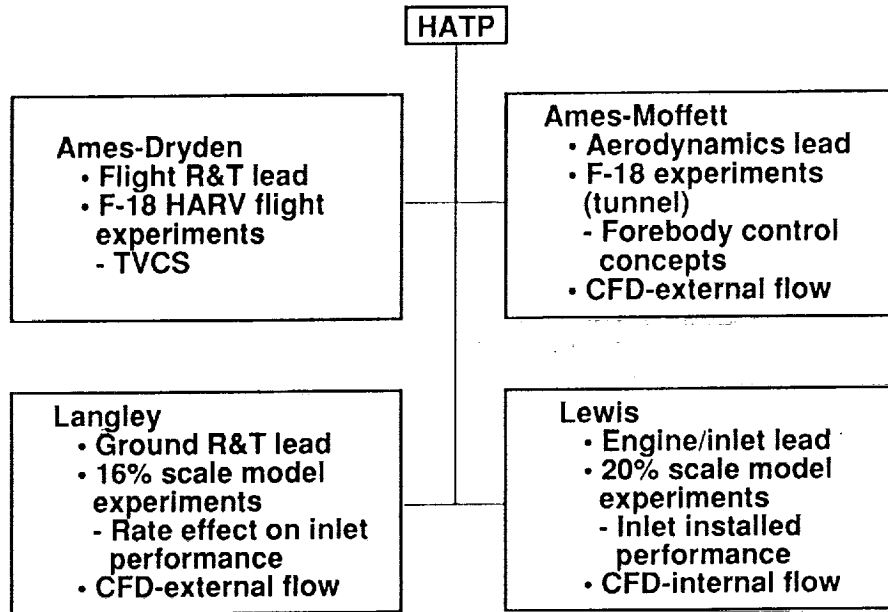191010778

HIGH ALPHA INLETS

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The high alpha inlet research effort at Lewis is part of the High Alpha Technology Program (HATP) within NASA. A key goal of HATP is to develop concepts that provide a high level of control and maneuverability for high performance aircraft at low subsonic speeds and angles-of-attack above 60°. The approach, which consists of both experimental and computational efforts, utilizes the F-18 High Alpha Research Vehicle (HARV) as well as subscale models to obtain the experimental data base needed for validation of the computational codes.

As the propulsion center within NASA, the overall objective of the Lewis effort is to develop and enhance inlet technology that will insure high performance and stability of the propulsion system during aircraft maneuvers at low speeds and high angles-of-attack. This paper presents an overview of the existing Lewis technology for achieving high inlet performance at low subsonic speed/high angle-of-attack conditions and the plans to extend this technology to advanced, highly maneuverable aircraft. The discussion is divided into six parts: (1) scope of the HATP effort, (2) the inlet challenge for highly maneuverable aircraft, (3) the Lewis data base, (4) the Lewis computational effort, (5) future plans, and (6) concluding remarks.

Scope of NASA High Alpha Technology Program (HATP)

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                         │ HATP │
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Ames-Dryden	Ames-Moffett
• Flight R&T lead • F-18 HARV flight experiments - TVCS	• Aerodynamics lead • F-18 experiments (tunnel) - Forebody control concepts • CFD-external flow

Langley	Lewis
• Ground R&T lead • 16% scale model experiments - Rate effect on inlet performance • CFD-external flow	• Engine/inlet lead • 20% scale model experiments - Inlet installed performance • CFD-internal flow

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The NASA High Alpha Technology Program is a cooperative effort involving Ames-Dryden, Ames-Moffett, Langley, and Lewis. Ames-Dryden is the lead center for flight research and technology. All experiments involving the F-18 HARV aircraft, including thrust vectoring control concept demonstration, will be conducted there.

Ames-Moffett is the lead center for aerodynamics. External flow experiments on a former Blue Angle aircraft without engines will be conducted in the 80- by 120-ft wind tunnel to develop forebody control concepts. Computer codes for predicting the external flow field of the F-18 HARV aircraft will be applied and evaluated.

Langley is the lead center for ground-based research and technology. Experiments will be conducted on a 16-percent scale model of the F-18 that will be pitched and yawed at high rates in the 14- by 22-ft wind tunnel to investigate the rate effect on inlet flow field and inlet performance. Computer codes for predicting the external flow field (steady state) of the F-18 HARV also will be applied and evaluated. These codes are different from those used by Ames-Moffett.

Lewis, as the propulsion center within NASA, is the lead center for the engine/inlet investigation. Experiments will be conducted in the 9- by 15-ft wind tunnel on an approximately 20-percent scale model of the HARV forebody/inlet to determine inlet-installed performance. Computer codes to predict inlet-installed performance will be applied and evaluated.
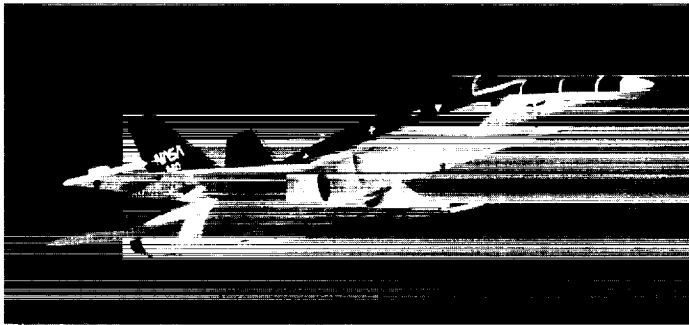
Inlet Challenge for Highly Maneuverable Aircraft

Challenge
- Reduce inlet distortion so engine does not stall
- Maintain adequate thrust for maneuverability

Types of inlet distortion for high alpha
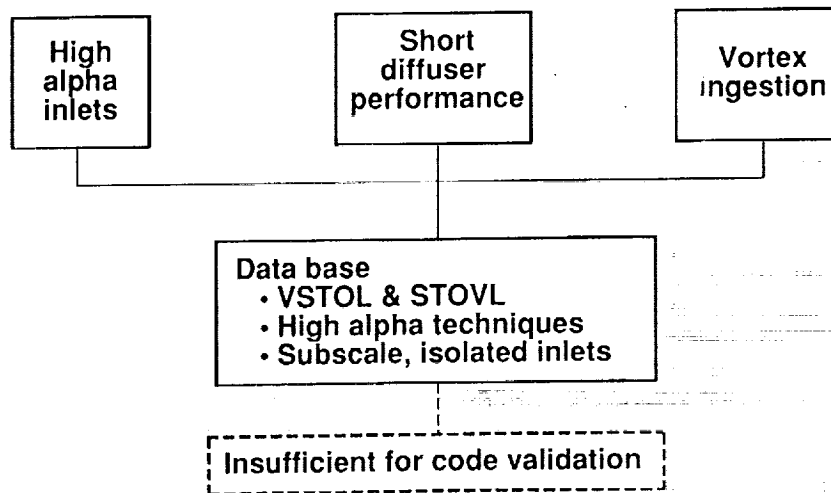- Total pressure
- Swirl

Vortex ingestion
Cowl lip separation
Diffuser
- Short/straight
- S-shape
Yaw rate at high alpha

CD-91-54027

The challenge for inlets that achieve high angles-of-attack is to design them to ensure efficient delivery of airflow to the engine during maneuvers. This ensures that the engine does not stall. It also ensures that an adequate thrust level is maintained so that, in postwing stall conditions, the aircraft is still fully maneuverable. Several different types of distortion must be considered in the design of these inlets. One type, total pressure distortion, can result when the inlet is at high angle-of-attack and/or yaw conditions. It can also be encountered when an inlet is attached to a short diffuser. Another type of distortion is caused by swirl, occurring when an inlet ingests a vortex shed from some part of the aircraft or inlet lip during maneuvers. Swirl can also be encountered when an inlet is attached to an S-shaped duct and is due to secondary flow generation in the duct. Steady-state distortion of the types just discussed will be presented in this paper.

Quasi-steady-state total pressure distortion can result from a yaw rate maneuver at high angles-of-attack. More will be said about this later. Instantaneous or dynamic total pressure distortion also must be considered but will not be presented in this paper.

5-3

Data Base

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┌──────────┐      ┌─────────────┐      ┌──────────┐
│  High    │      │   Short     │      │  Vortex  │
│  alpha   │      │  diffuser   │      │ ingestion│
│  inlets  │      │ performance │      │          │
└────┬─────┘      └──────┬──────┘      └────┬─────┘
     │                   │                  │
     └───────────────────┼──────────────────┘
                         │
        ┌────────────────┴──────────────────┐
        │ Data base                         │
        │   • VSTOL & STOVL                 │
        │   • High alpha techniques         │
        │   • Subscale, isolated inlets     │
        └────────────────┬──────────────────┘
                         │
        ┌ ─ ─ ─ ─ ─ ─ ─ ─┴─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
        │ Insufficient for code validation  │
        └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
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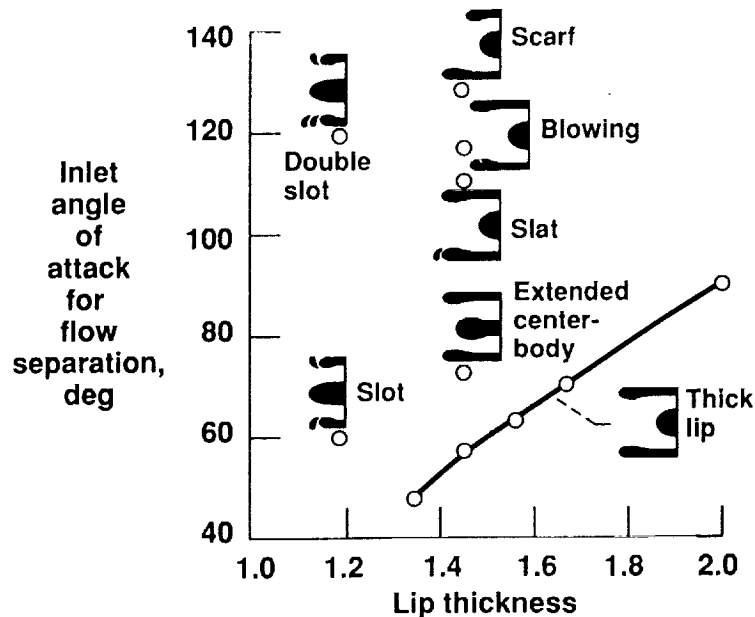
CD-91-54028

The existing data base includes past experiments to increase inlet angle-of-attack capability, improve the performance of very short, straight diffusers, and investigate the effect of ingesting vortices on engine stall. The effect of vortex ingestion is reported in reference 1. Short, straight diffuser performance was discussed in a previous paper by Peter Batterton. A sample of the data base to increase inlet angle-of-attack capability will be discussed in this paper.

The data base has been generated over the past 20 years primarily in support of subsonic and supersonic VSTOL and STOVL aircraft at low subsonic speeds and high angle-of-attack conditions. Techniques have been defined that have the potential for achieving high inlet performance at these conditions. However, the data base contains results only from subscale, isolated inlet configurations. Thus, the data base is not yet sufficient for code validation.

Data Base (continued)
High Alpha Subsonic Inlets

Free-stream Mach number = 0.12


A wide variety of isolated, mostly axisymmetric, subsonic inlet concepts have been tested to high angles-of-attack at low free-stream Mach numbers, as shown in this figure taken from reference 2. Desirable inlet characteristics are thin lips, to achieve both light weight inlets and good cruise performance, and high separation angles, to help insure that the aircraft maneuvers do not result in engine stall.

Techniques for achieving high angle-of-attack, shown in the figure, include increasing the lip thickness, extending the centerbody, extending the lower (windward) lip, employing active boundary layer control by tangential blowing near the inlet throat, and employing three passive boundary layer control concepts. Although increasing the lip thickness increases angle-of-attack capability, this is moving away from the goal of thin lips. For moderately thin lips, scarfing the inlet by extending the lower lip is an attractive technique. The inlet with the thinnest lip and the highest angle-of-attack capability tested employed a passive boundary layer control technique that combined a slat with a slotted inlet and was called the double slot inlet.

Data Base (continued)
2–D Supersonic Inlet in 9– by 15–ft Tunnel

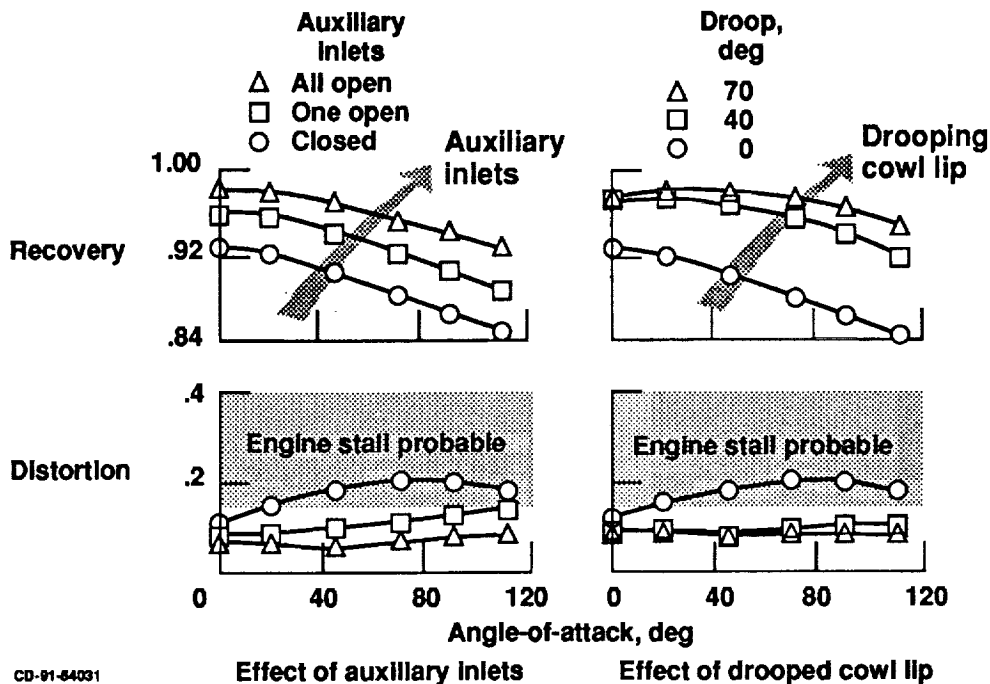**Bottom auxiliary inlet**

70° Drooped cowl lip
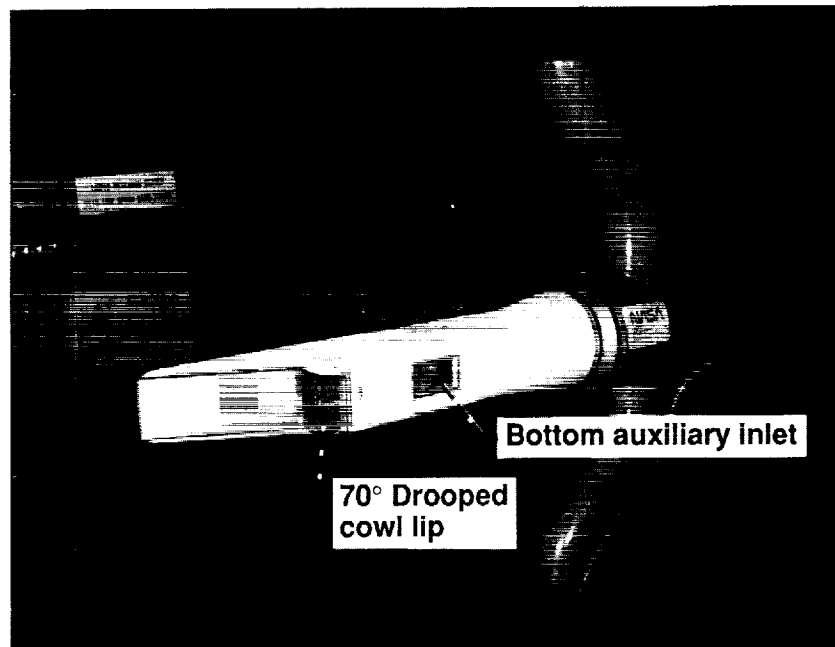
CD-91-54030

In addition to subsonic inlets, a supersonic inlet has been tested subsonically over a large range of angles-of-attack. The experimental model is shown in this figure installed in the 9- by 15-ft low speed wind tunnel. The model is a two-dimensional two-ramp inlet designed for a Mach number of 2.2.

Two different techniques were investigated for improving inlet performance at low speed/high angle-of-attack conditions: (1) drooping the cowl lip and (2) opening the auxiliary inlets located on each of the four sides of the main inlet. For illustrative purposes, the figure shows the cowl lip drooped to 70° and the bottom auxiliary inlet open. The tests, however, were conducted with either the cowl lip drooped or the auxiliary inlets open, but not in combination with each other. More details of the inlet model are given in reference 3.

Data Base (concluded)
High Alpha 2–D Supersonic Inlet
Free-stream Mach number = 0.12

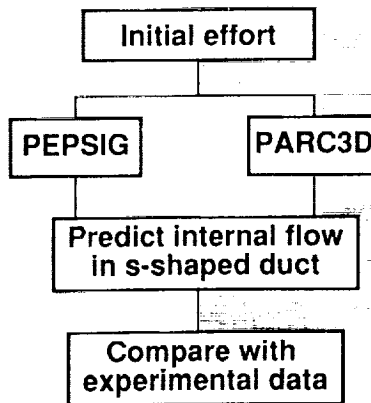Effect of auxiliary inlets   Effect of drooped cowl lip

The effect of either opening the auxiliary inlets or drooping the cowl lip on inlet performance over a range of angles-of-attack from 0 to 110° at a free-stream Mach number of 0.12 is shown in this figure from reference 3. Performance is given in terms of recovery (engine face average total pressure divided by free-stream total pressure) and distortion (engine face maximum total pressure minus engine face minimum total pressure divided by engine face average total pressure). Total pressure distortion values above 15 percent are generally considered unacceptably high for initial screening purposes.

High performance at low subsonic speed/high angles-of-attack can be achieved by either opening the auxiliary inlets or drooping the cowl lip. The best performance was achieved with the 70° drooped cowl lip. Recovery was high, above 96 percent for angles-of-attack up to 100°, and distortion was low at 8 percent. If the cowl lip was not drooped (or the auxiliary inlets were not opened), the inlet would be limited to angles-of-attack below about 20° to stay within the acceptable level of distortion.

In summary, the data base contains only a limited number of steady-state pressure measurements obtained on subscale isolated inlet configurations. Consequently, the data base is not yet sufficiently complete for evaluating computer codes. However, the data base will be extremely useful in defining inlet configurations and techniques that have the potential for achieving high performance at low subsonic speed/high angle-of-attack conditions.

Computational Effort

- **A key goal is to predict internal performance of installed inlets at high alpha**

- **Use internal/external flow codes since internal performance effected by external flow**

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        ┌──────────────────┐
        │   Initial effort │
        └──────────────────┘
            │         │
     ┌──────────┐  ┌──────────┐
     │  PEPSIG  │  │  PARC3D  │
     └──────────┘  └──────────┘
            │         │
        ┌──────────────────────┐
        │ Predict internal flow│
        │    in s-shaped duct  │
        └──────────────────────┘
                   │
        ┌──────────────────────┐
        │     Compare with     │
        │  experimental data   │
        └──────────────────────┘
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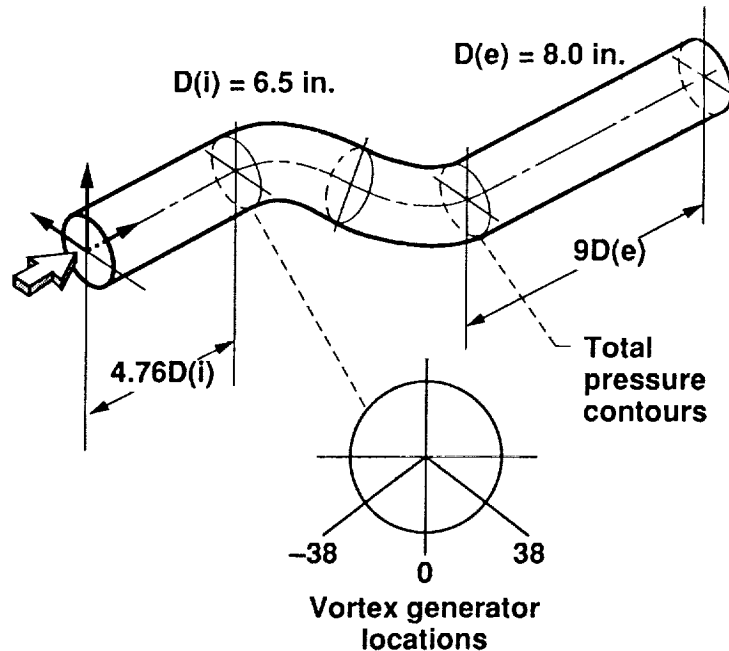
CD-91-54032

One of the key goals of this program is to calibrate/validate computer codes that can be used to predict the internal performance of installed inlets at high angle-of-attack conditions. Internal performance of installed inlets will be influenced by the external flow field upstream of the inlet. Thus, it will be necessary to use both internal as well as external flow codes. As a first step in the process, Lewis has been concentrating on two codes: PARC3D (ref. 4), the full Navier-Stokes code which can be used to predict external as well as internal flow fields, and PEPSIG (ref. 5), a parabolized Navier-Stokes code which can be used to predict internal flow fields.

Lewis computational capability will be illustrated using PARC3D and PEPSIG codes to predict the complex flow in an S-shaped diffusing duct. Predicted results are compared with experimental data taken from reference 7.

# Computational Effort (continued)
Diffusing S–Duct

A(exit)/A(inlet) = 1.5; M(inlet) = 0.6

D(e) = 8.0 in.

D(i) = 6.5 in.

9D(e)

4.76D(i)

Total pressure contours

−38   38
0

Vortex generator locations

CD-91-54033

A sketch of the S-shaped diffusing duct is shown here. It has a circular cross section with two 30° bends resulting in a vertical offset of about one inlet duct diameter. The duct has an entrance diameter of 6.5 in. and an exit diameter of 8 in. resulting in a diffusing area ratio of 1.5. Inlet Mach number was 0.60. Flow separation and reattachment occurred in the duct, which also had strong secondary flow similar to that observed in some aircraft inlets. For some tests, three pairs of counter-rotating circular arc vortex generators were installed in the duct just downstream of the entrance near the bottom of the duct at circumferential angles of -38, 0, and 38°, as shown in the figure. The vortex generators were set at an angle-of-attack of 16° to the axial direction.

Computational Effort (continued)
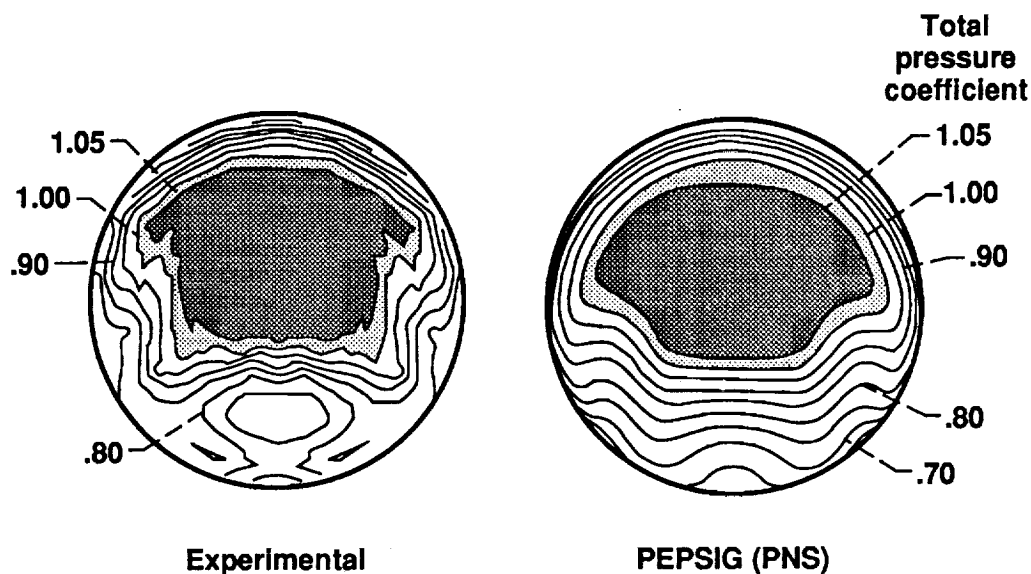## Surface Static Pressure Distribution
No Vortex Generators
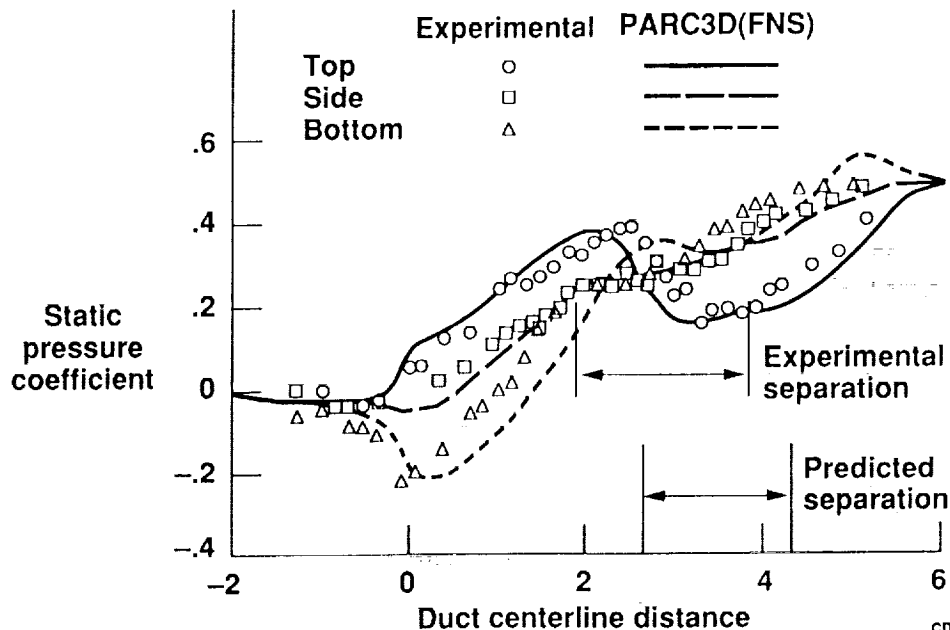
The predicted surface static pressure distribution from the PARC3D code at three circumferential locations is compared to the experimentally measured distribution in this figure in terms of the static pressure coefficient (local surface static pressure minus free-stream static pressure divided by free-stream dynamic pressure). Vortex generators were not installed and, consequently, flow separation occurred in this duct. Predicted flow separation occurred about one-half of a duct diameter downstream of the actual separation location. Also, the predicted static pressure distribution did not agree very well with the experimental distribution.

Three factors contribute to this discrepancy. Two of them, grid resolution and turbulence modeling, can affect the generation of vorticity and viscosity respectively. The third factor is the large tolerance of the internal surface of the duct walls. This factor resulted in some waviness of the internal surface of the experimental model compared to the smooth internal surface of the computational model. This data base, however, is one of the few available that contains very useful information on high subsonic flows in S-ducts.

Computational Effort (concluded)
Total Pressure Contours With Vortex Generators

Total pressure coefficient

Experimental labels: 1.05, 1.00, .90, .80

PEPSIG (PNS) labels: 1.05, 1.00, .90, .80, .70
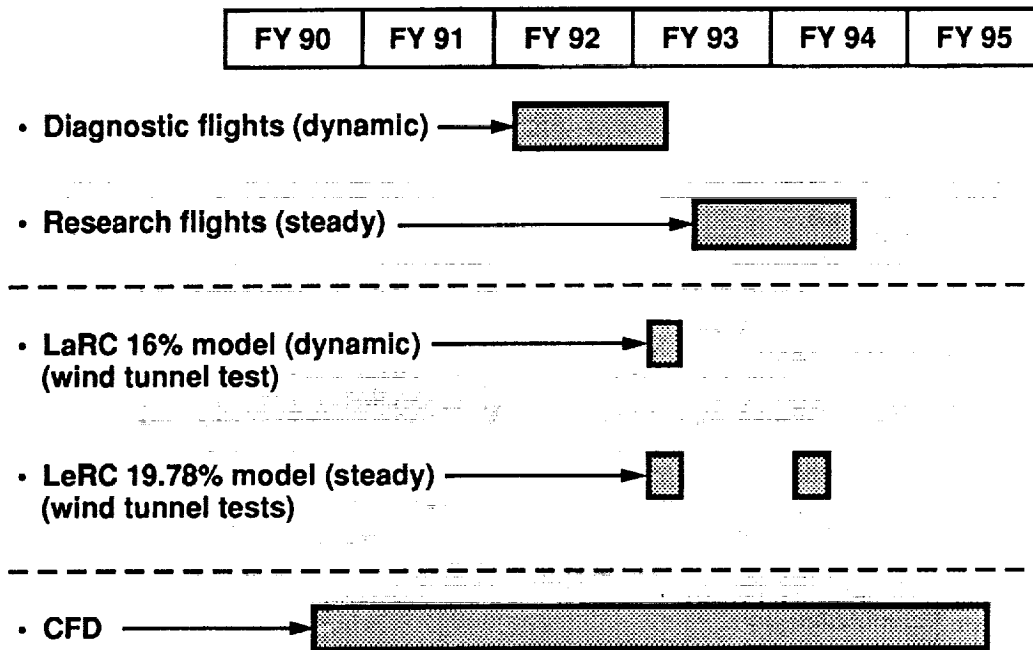
Experimental   **PEPSIG (PNS)**

CD-91-54035

In addition to a static pressure distribution, a comparison of total pressures was made and is shown in this figure for installed vortex generators. The predicted total pressure contour at the duct exit is compared with the experimental contour in terms of a total pressure coefficient. (Total pressure coefficient is defined as the local total pressure minus the free-stream static pressure divided by the free-stream dynamic pressure.) Predicted results were obtained using the PEPSIG code, which models the vortex generators in terms of a vorticity signature calculated from the physical properties of the generators themselves. Concentration of low total pressure near the bottom of the duct and high total pressure near the top of the duct is typical of that in S-ducts.

The agreement between predicted and actual total pressure contours is fairly good. However, the predicted region of low energy flow is somewhat smaller and the high energy flow region is somewhat larger than that of the experimental contour. Also, the predicted counter-rotating vortices near the bottom of the duct are less evident than in the actual flow. These discrepancies could be due to grid resolution, turbulence modeling and/or vortex generator modeling which can affect the generation of vorticity and viscosity.

In summary, these results are encouraging. There are, however, difficulties associated with the prediction of turbulent three-dimensional flows that contain strong secondary flows as well as separated flows. Further studies using denser grids as well as higher order turbulence and vortex generator models may improve these predictions.

Future Plans — Inlets

FY 90	FY 91	FY 92	FY 93	FY 94	FY 95

- **Diagnostic flights (dynamic)** ━━▶ ▨

- **Research flights (steady)** ━━━━━━━━▶ ▨

- **LaRC 16% model (dynamic)** ━━━━━▶ ▨
  (wind tunnel test)

- **LeRC 19.78% model (steady)** ━━━━━▶ ▨   ▨
  (wind tunnel tests)

- **CFD** ━━━━━━▶ ▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨▨

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Future plans for inlet tests are divided into the three categories of F-18 HARV flight tests, subscale tests, and computational effort (CFD), as shown in the figure. Flight tests are subdivided into diagnostic and research flights. Diagnostic flights, scheduled for about 1 year starting in the first quarter of FY 92, will investigate why F-18 aircraft experienced thrust losses when performing dynamic maneuvers outside the normal flight envelope during the Navy envelope expansion program. This effort will be followed by research flights also lasting about 1 year, which will generate a limited inlet steady-state data base for code evaluation.

Subscale model tests will be conducted at NASA Langley and Lewis. A 16-percent scale model F-18 HARV scheduled for a 6-week test in the Langley 14- by 22-ft tunnel, starting about the first quarter of FY 93, will investigate the effect of pitch and yaw rates on inlet flow field and inlet performance. The results will be compared with data from the diagnostic flights. A 19.78-percent scale model of the F-18 HARV forebody/inlet scheduled for two 6-week tests in the Lewis 9- by 15-ft tunnel (the first in FY 93 and the second in FY 94) will generate an inlet steady-state data base for code evaluation. These results will be compared with the more limited data base from the research flights.

The computational effort has already started and will continue into FY 95. It will be directed principally towards predicting the internal performance of the installed HARV inlet at high angles-of-attack. The codes will be evaluated and improved using the experimental data base generated from both flight and subscale model tests.

CONCLUDING REMARKS

This paper has described the existing Lewis technology for achieving high inlet performance at low subsonic speed/high angles-of-attack conditions and the plans to extend this technology to advanced highly maneuverable aircraft. Both the existing technology and the future plans include experimental as well as computational parts.

The experimental part of the existing technology consists of a data base generated over the past 20 years primarily in support of subsonic and supersonic VSTOL and STOVL aircraft at low subsonic speed/high angle-of-attack conditions, and contains results principally from subscale, isolated inlet configurations. Attractive techniques for achieving high performance at low subsonic speed/high angle-of-attack conditions have been shown. The data base, however, does not contain sufficient information for a complete evaluation of computer codes.

The computational part of the existing technology consists of results principally from studies using an S-shaped diffusing duct with and without vortex generators. Flow separation and reattachment occurred in this duct, which also had a strong secondary flow. The full Navier-Stokes code, PARC3D, and a parabolized Navier-Stokes code, PEPSIG, were used to predict the complex flow field within the duct. The results are encouraging. Further studies with denser grids as well as the use of higher order turbulence and vortex generator models may improve the prediction capability.

Future plans include both experimental and computational efforts applicable to external and internal flows associated with the F-18 HARV as well as with a subscale F-18 model at low subsonic speed/high angle-of-attack conditions. The experimental effort will be directed principally towards expanding the existing data base to include detailed information on forebody/inlet flow field interaction and its effect on inlet performance. The computational effort will be directed principally towards predicting the internal performance of the installed HARV inlet at high angles-of-attack. The codes will be evaluated and improved using the experimental data base generated from both flight and subscale model tests.

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